NOTES ON THE MANUFACTURE OF FLAT PLYWOOD

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Plywood is manufactured by bonding thin sheets of wood (veneers) together with adhesives in such a way that the mechanical and physical properties of the wood are redistributed. The manufacture of plywood requires special equipment, knowledge, and technique. It is the purpose of this paper to outline the important steps in the process of making flat plywood. These notes on manufacture are based upon observations of factory practice and upon extensive experiments at the Forest Products Laboratory.

The Components of Plywood

The essential components of plywood are veneer and adhesives. Both are available to the plywood manufacturer in several grades and types.

Veneer

Veneer consists of thin sheets of wood, ranging in thickness from 1/100 inch to occasionally more than 1/4 inch. It is cut from many kinds of wood, both softwood and hardwood species, and is classified by species and grades.

Veneer must be smoothly cut, uniform in thickness, flat, and uniformly dried, for plywood manufacture. The desirable moisture content for veneer at the time it is glued varies with the type of glue used and the conditions the finished plywood will encounter in service, but in any case the distribution of moisture should be uniform throughout the veneer.

Veneer for most kinds of plywood should be low in moisture at the time of gluing so that, when it is removed from the press, the moisture content, increased by the moisture from the glue, will be near to the optimum for ultimate use. For fancy, cross-grained veneer, gluing at low moisture content is of particular importance, since drying of the panel from high moisture content frequently results in checking of the face ply. Glues not water-resistant also require the use of low moisture content veneer, but with water-resistant glues it is possible to use veneer of somewhat higher moisture content. With the synthetic resin glues, best results are obtained with veneer at a moisture content ranging from 2 to 12 percent, depending upon the particular glue being used.

The moisture content of veneer is controlled by (1) drying the veneer in a regulated veneer drier shortly before gluing, (2) storing the veneer in temperature and humidity controlled rooms, or (3) running the veneer through redriers before gluing.

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The temperature of veneer at the time of gluing is important. When veneer is taken directly from driers or redriers and assembled into plywood at too high a temperature for the glue, there is danger of impairing the quality of the plywood panel. This condition can be controlled only by knowing the upper limits of temperature permissible and by holding back any veneer that exceeds that temperature until it has cooled.

Selection of Veneer

The quality and usefulness of plywood depends largely upon the quality of the veneer from which it is made. In plywood for aircraft or other structural purposes, it is necessary to avoid or closely limit the defects that affect the strength or durability of the plywood. The strength properties of the wood species used must also be taken into consideration. In plywood for the visible parts of furniture, interior trim, and similar purposes, the principal consideration is appearance and hidden defects that do not impair the appearance are generally acceptable.

Adhesives

The adhesives available for bonding veneers together to make plywood panels are conveniently classified according to the temperature at which they set and the degree of water resistance which they manifest after setting.

On the basis of setting temperature, these adhesives fall into three general groups: (1) Most phenol-formaldehyde and melamine-formaldehyde glues, which require temperatures of 200° to 300° F. and are usually set between heated plates; (2) some urea-formaldehyde and low-temperature phenolic glues, which require moderate temperatures of about 90° to 160° F. and can be set in a room or kiln with controlled temperature, and (3) cold-setting urea glues that set at 75° F. or above and casein, soybean, and starch glues, which will set at ordinary room temperatures.

The extremes of water resistance are illustrated by starch glue, with no appreciable water resistance, used for interior work; and phenolic-resin adhesives, used for plywood which will withstand continuous soaking or exposure under exterior conditions.

The Gluing and Pressing Operations

The problem of applying the glue is principally one of applying an even spread of the desired thickness on the surface of the veneer quickly enough so that the veneer and glue assembly may be placed under pressure before the glue begins to set.

When using glue in liquid form, the core or crossbands of the panels are usually coated on both faces with the glue by means of a mechanical roll spreader. Scrapers, idler rolls, or the pressure of the main rolls regulate

the thickness of the glue layer, according to the character of the spreader being used. Spreaders for vegetable and casein glues usually have corrugated iron rolls, while rubber covered rolls with fine corrugations are ordinarily required for resin glues in liquid form. Most liquid glues can also be spread with brushes or scrapers in small gluing operations and some resin glues can be applied by spraying.

Some resin glues are available in the form of dry films. Such glues do not need a spreader for the dry film cut to proper size can be inserted between the sheets of veneer.

As the glue is spread, the veneers are assembled in relationship to each other as required in the finished panel.

It is standard practice in plywood manufacture to place the grain of adjacent plies perpendicular to each other and to use an odd number of plies so that corresponding plies are located at the same distance from, but on opposite sides of, the center or core ply. It is also important that opposite plies be of the same thickness and same species; or be of species having similar shrinking, swelling, and strength characteristics.

Plywood for special purposes, such as certain aircraft uses, may be laid with the grain of alternate layers at angles other than 90 degrees with each other or with the edges of the panel. Such special plywood does not always have an odd number of plies. These constructions, however, must be regarded as infrequent exceptions.

In three-ply panels the outside plies are referred to as faces and the center ply as a core. In five-ply construction the outside layers are faces, the first inside plies are crossbands, and the center ply is the core. In panels with larger numbers of plies, there is no special name for the plies that lie between the center ply (core) and the crossbands that are adjacent to the faces.

When the glue and veneer are properly assembled, they are put under pressure. There are two general types of pressing equipment in common use -- the hot-plate press and the cold press.

Hot Pressing

Much plywood gluing is now being done in hot presses, particularly when high water resistance is required. At the present time all gluing with film glues, practically all gluing with phenolic-resin glues, and much gluing with urea-resin glues is done in hot presses. Soybean glues, and blends of soybean and blood glues, are used extensively in hot-plate presses for moisture-resistant plywood production in the Douglas-fir plywood industry. Straight blood glues also give their best results when used in hot presses.

In hot pressing thin plywood, several panels may be placed together between the heated plates. With thick panels, only one panel is pressed in each opening. Hot presses usually have many plates, so that a number of

panels can be glued in one pressing operation. When gluing panels with thin faces, the press must be closed promptly after inserting the panels, in order to avoid partial setting of the glue before pressure is applied.

The time required in the hot press depends upon the thickness of the material being glued and upon the character of the glue being used. Some glues require setting temperatures in the neighborhood of 300° F., while others can be cured at 212° F. or lower. Since the innermost glue line must be heated to the required temperature, the pressing time depends upon the distance the heat must travel from the plates to reach this glue line. The time may vary from 2 or 3 minutes for very thin panels to an hour or more for panels 2 or 3 inches thick. The time required can be calculated by the use of mathematical formulas which consider wood thickness, species, moisture content, press temperature, and setting temperature of the glue. Charts, from which the rate of heating of a panel may be determined, are available.[1] Glue manufacturers can usually furnish specific recommendations for obtaining best results with their respective glues.

The amount of pressure required in hot-press gluing varies with the kind of wood being glued. Heavy, dense woods can stand higher pressures than lighter, softer woods. For most species of wood, pressures of 150 to 200 pounds per square inch are adequate. The pressure used should generally be below the crushing strength of the wood.

In hot-pressing plywood, the veneer is likely to lose considerable moisture during and immediately after pressing, which favors checking and warping. It is customary, therefore, to add moisture after pressing at high temperatures, either by applying water to the panels immediately after removal from the hot press and stacking them in solid piles, or to expose them to controlled humidities. Other methods, some of them patented, are also used.

Cold Pressing

With glues that are pressed without heating, the panels are stacked and placed in the press as soon as possible after applying the glue. The actual time permitted between spreading glue on the first veneer and the application of pressure to the stack of panels must be definitely limited, although it varies with different glues from several minutes to a half hour or longer. The panels are accumulated in a pile up to 30 inches or more in height, with flat caul boards separating the pile into groups of 2 to 7 or more panels. Rigid, smooth, press boards are put on top and bottom of the stack of panels and the assembly is placed under pressure.

In cold pressing, two methods are used extensively in applying the pressure and maintaining it on the panels. The one most commonly used consists of applying the pressure by a hydraulic press and then using retaining

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[1] Forest Products Laboratory Mimeograph R1299, "The Rate of Temperature Change in Wood Panels Heated Between Hot Plates."

clamps to keep the panels under pressure. The hydraulic press is usually equipped with a gage to show the amount of pressure applied. The panels are left in the hydraulic press just long enough to apply the proper load and fix the retaining clamps in place. The bundles of panels are then removed on a truck to an out-of-the-way place in the factory where they are usually left until the next day.

By the other method, the panels are placed in presses and left until the glue is set. These presses are usually of the hand screw type with no means for accurately measuring the amount of pressure applied.

Control of pressure is important in all pressing operations. The exact amount of pressure to apply per square inch of panel surface varies with a number of conditions. However, under average factory conditions good results may be obtained with most glues at pressures of 100 to 250 pounds per square inch of panel surface.

The determination of the amount of pressure applied per square inch of panel on a hydraulic press equipped with a pressure gage is simply a matter of calculation. The principal factors that determine the amount of pressure applied are: the area of the panel, the area of the piston or ram of the press, and the pressure gage reading. The area of the piston in square inches multiplied by the pressure gage reading in pounds is approximately equal to the total load exerted by the plates. The total load exerted divided by the area of the panel in square inches gives the approximate pressure secured on the panel in pounds per square inch. To obtain exact pressures on the panels it is necessary to correct the above calculations for the weight of the movable parts of the press, which may increase or decrease the pressure applied, depending on the design of the press. For large presses and small panels this is important.

A table, showing gage readings to be used for all sizes of panels manufactured and for the different pressures used, can be computed and placed near the press where the operator may see at a glance the amount of pressure required on the gage reading for each run of panels.

Conditioning and Finishing of Plywood Panels

When the glue is set, the pressure is released and the plywood panels are removed. The panels may be ready to trim and sand at once or may require redrying before further work is done on them.

Panels glued cold with the common types of aqueous glues take up a good deal of moisture in gluing and, after coming from the press, are often placed on stickers and run into a kiln or left at room conditions for final drying. Drying under room conditions is slow and is expensive because of the space required.

Results of experiments in kiln drying panels have indicated that the essential requirements of minimum injury to the material and convenience and

economy of operation can be met by maintaining a constant temperature of about 120° F. and a constant maximum relative humidity which will permit the stock to dry down to the desired moisture content in a relatively short time but which will not allow appreciable drying below this point. The use of constant temperature and humidity conditions which will dry the panels to a definite moisture content makes the drying simple and safe. For panels of three- and five-ply veneer, or of veneer faces crossbanding and a thick core, glued at a low moisture content, drying at 120° F. and the necessary humidity may be accomplished in a few hours or overnight. Temperatures above 120° F. have the advantage of decreasing the drying time, but they are more liable to lower the quality of the panel by inducing checking, warping, and open joints, unless the humidity is carefully controlled. Panels dried from a high to an extremely low moisture content are liable to warp unless they are dried relatively slowly.

Trimming and Sanding

The plywood panels are trimmed on standard ripping and cut-off equipment. The equipment must be in good condition and accurately set up, otherwise the panels will not be square.

The trimmed panels are usually sanded, and this too is a critical operation. Most of the care given to making a perfectly balanced panel by selecting veneer of uniform thickness, moisture content, and suitable species, is wasted if improper finishing sands one face thinner than the other.

Storage

Finished plywood panels should be stored under conditions that will not appreciably change their moisture content. Stacking in solid piles with the panels directly over each other and a solid cover over the top of each pile protects the panels against rapid changes in moisture content, warping, dust accumulation, and discoloration due to light.

Factors Affecting the Warping of Plywood

Symmetrical Construction

A plywood panel to retain its form, with moisture changes, must be symmetrically constructed. Symmetry is obtained by using an odd number of plies. The plies should be so arranged that for any ply of a particular thickness there is a parallel ply of the same thickness and of the same species or properties on the opposite side of the core and equally distant from the core.

A change in moisture content of plywood will inevitably either introduce or relieve internal stresses because of the great difference in shrinkage of wood in the direction parallel to the grain and perpendicular to it.

A three-ply construction subjected to a low humidity so that the moisture content of the plywood is lowered illustrates how internal stresses may act. When the grain of the core is at right angles to the grain of the faces, the normal shrinkage of all plies across the grain is largely prevented by a very small change in dimensions of the adjacent ply or plies in the direction of the grain. If the faces are of exactly the same thickness, of like density, and otherwise balanced, the stresses are symmetrically distributed and no cupping will ensue.

If one face of a three-ply panel has been glued with the grain in the same direction as the core, and the moisture content of the panel is reduced, the internal stresses are no longer symmetrically distributed inasmuch as the one face ply does not restrain the core ply from snrinking while the other does. Cupping takes place as a result.

Twisting is another form of warping that may be encountered in the manufacture of plywood. Tests have shown that deviations as small as 5 degrees between the grain of any two corresponding plies, such as crossbands, may introduce considerable twisting. One method of eliminating twisting is to cut the veneer sheets so that the direction of the grain is parallel to the edges of the sheets. The direction of grain may be tested by splitting the veneer or by other suitable means. It is not always convenient or possible to cut the veneer in the exact direction of the grain. In such cases, the tendency to twist may be eliminated if the veneers are so glued that the grain of opposing plies is parallel even though its direction is not exactly perpendicular to that of the core. This matching of plies may be accomplished most easily when sliced veneer is used and pieces which were adjacent in the flitch are glued on opposite sides of the core so that they have the same relative position as they had in the flitch. When maximum freedom from warping is required and rotary-cut veneer is used, it may be necessary to examine each sheet to make sure it is laid in the correct position.

If veneered panels are being built up of five or more plies, the direction of the grain of the crossbands is the most important factor in preventing twisting. The faces of five-ply veneered stock may exert some influence in causing or preventing twisting, but it is not so marked as the influence of the crossbands.

Moisture Control

The previous discussion brought out the fact that a change in moisture content of a panel may introduce cupping and twisting in the panel if it is not carefully constructed. Hence, it is highly desirable that all plies, particularly the faces and crossbands, be at about the same moisture content before gluing. The moisture content of the panel as it leaves the drying room should be about the same as it will average when in use. A moisture content of 10 to 15 percent in the finished panel will usually give satisfactory results for a panel to be in service in the open air. For use within buildings heated at least a part of the year, as in furniture, a somewhat lower moisture content of 7 to 8 percent will ordinarily give best results.

Relation of Density of Veneer to Warping

Numerous tests have shown that the warping of plywood panels when subjected to varying moisture contents is least for the panels made of low-density veneer, such as basswood, poplar, and cedar, and that, in general, warping increases with increasing density.

Effect on Warping of Increasing the Thickness Ratio of the Core to the Total Plywood

A high proportion of core to total plywood thickness helps to maintain a flat unwarped surface. In general, the core of a three-ply panel should be 5/10 to 7/10 of the total thickness of the panel where flatness is an important consideration. Increasing the number of plies in a panel of given thickness also reduces the tendency to warp.

Specifications

The quality of plywood and of the veneer from which it is made is for some purposes covered by specifications. Aircraft plywood, for example, is covered by an Army-Navy Aeronautical specification. There are two commercial standard specifications -- one covering Douglas-fir plywood and the other covering hardwood plywood. Some purchasers or producers have their own specifications. Current government specifications for flat plywood for aircraft use and the commercial standards in effect (April 1943) are as follows:

Army-Navy Aeronautical Specification AN-NN-P-511b -- Plywood and Veneer; Aircraft Flat Panel

Commercial Standard CS 45-42 -- Douglas-fir Plywood (Domestic Grades)

Commercial Standard CS 35-42 -- Plywood (Hardwood and Eastern Red Cedar)

References

This mimeograph necessarily contains only a limited amount of the information available on the manufacture of plywood. A more thorough introduction to the subject can be obtained by consulting the publications listed below:

"Modern Plywood," Thomas D. Perry, published by the Pitman Publishing Company, 2 West 45th Street, New York City, price $4.50. (1942)

"Plywoods, Their Development, Manufacture, and Application," A. D. Wood and T. G. Linn, published by W. and K. Johnston, Edinborough, Scotland, price $6.50. (1942)

"Technique of Plywood," C. B. Norris, published by I. F. Laucks, Inc., Seattle, Washington, price $2.50. (1942)

"Some Causes of Warping in Plywood and Veneered Products," Don Brouse, Forest Products Laboratory Mimeograph R1242. (1940)

"The Gluing of Wood," T. R. Truax, U. S. Dept. of Agr. Bulletin No. 1500.

"List of Publications on Glue and Plywood," Forest Products Laboratory Mimeograph No. 513. (1940)